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Semi-Annual Status Report

for

NASA Grant NGR 43-001-135

PROGRAM TO STIMULATE GRADUATE TRAINING IN THE FIELD OF AEROACOUSTICS

March 1, 1974 - September 1, 1974

THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE
Tullahoma, Tennessee

Prepared by

James R. Maus
James R. Maus
Associate Professor of
Engineering Science and
Aerospace Engineering

Robert S. Becker
Robert S. Becker
Graduate Research Assistant

(NASA-CR-140793) PROGRAM TO STIMULATE GRADUATE TRAINING IN THE FIELD OF AEROACOUSTICS Semiannual Status Report, 1 Mar. - 1 Sep. 1974 (Tennessee Univ. Space Inst., Tullahoma.) 24 p

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Introduction

Under NASA Grant NGR-43-001-135, The University of Tennessee Space Institute is engaged in a program to stimulate graduate training in the field ao aeroacoustics. A Ph. D. candidate, Mr. Robert S. Becker, will be supported for three years of academic and research training at The University of Tennessee Space Institute, including up to one year of research in the facilities at the NASA Lewis Research Center. This report is a status report covering the second six months of this graduate training program.

As outlined in the previous status report, the principle research effort of the student investigator will be directed toward the acoustic and fluid dynamic characteristics of jet blown flaps. The primary technique that will be used to establish a direct relationship between the flow field and the acoustic far field is the cross correlation of the outputs of a hot wire probe in the flow field and a microphone in the acoustic far field. This experiment will be conducted in the anechoic facility at the Lewis Center. In preparation for the cross correlation research at Lewis, some preliminary work has been carried out in this area at UTSI. Part Two of this report deals with this effort.

In addition to the direct causality-type relationship established by cross correlation, knowledge of general flow-field structure is needed to explain the mechanics of sound generation. Part One of this report contains the results of flow-field measurements taken to the rear of the trailing edge of rough and smooth flaps which are blown by a slot nozzle. Two flow-field parameters, mean velocity and turbulence intensity, are measured and compared for rough and smooth flap configurations.

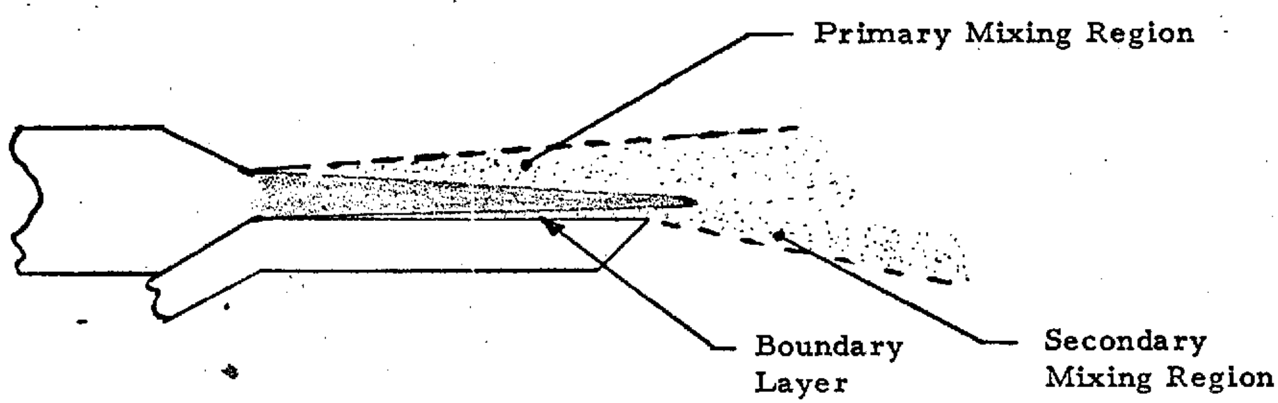
Part I - Flow Field Measurements

For many years it has been known that perturbing jet flow at or upstream of the exit plane produces a change in the turbulent structure of the ensueing jet. Screens used in bunsen burners are a common example of this turbulence modification. Moreover, it has been shown [1] that jets which are perturbed by nozzle corrugations generate less noise than their unperturbed counterparts.

In the area of blown jet flaps, Yee [2] did an extensive comparison of acoustical characteristics of smooth and rough flap configurations. The results of this study showed that for almost every flap geometry, there was both a reduction in the sound power generation,and a change in the radiation directivity. In no case was there an increase in the sound power generation. Yee's tests were performed over a Mach number range of 0.5 to 0.9 for various flap roughnesses. The maximum sound power reduction caused by flap roughening was found to be about 4 dB. In view of these results, it was of interest to determine the fluid dynamic effects of roughing by using hot wire measurements. The measurements were confined to the flow field at and to the rear of the flap trailing edge, in order to study the secondary mixing region, which Schecker [3] has shown to be a major sound producer.

Test Set Up

The apparatus used for these tests is a small (approx. $.1 \times 1.3$ in^2) slot nozzle, with an attached .795" flap. Air is brought into a 4 inch



Jet Flap and Expected Aerodynamic Noise Sources diameter stilling chamber and is allowed to expand isentropically to the atmosphere. Roughening of the flaps is effected by gluing number 80 sandpaper on the flap surface. Care was taken to ensure that the attached sandpaper did not obstruct the exit plane of the nozzle and hence reduce the mass flow. A schematic of the test set up is shown in Figure la. The flap width out of the plane of the page is greater than the corresponding slot nozzle width. The hot wire probe was positioned parallel to the flap surface and values of L are measured from the tip of the flap. Finally, the probe linearization is such that each volt on the mean velocity scales is equivalent to approximately 10 meters per second.

Results

Figures lc through lg are the comparisons of mean velocity and turbulence intensity for rough and smooth flaps. These profiles are measured at various distances downstream of the flap trailing edge. Figure lb represents the smooth flap case, only, since it was impossible to traverse that closely to the roughened flap without danger of damaging the probe. In all figures, there is a reduction in the turbulence intensity of both the secondary mixing region and the primary mixing region aft of the trailing edge. All though to date tests are not complete, there is good reason to suspect the trubulence intensity in the primary mixing region forward of the flap trailing edge is also reduced.

It should be said parenthetically that in general there are three different cases of blown jet flow.

1. The end of the potential core of the jet is well forward of the flap trailing edge.
2. The end of the potential core is well aft of the trailing edge.
3. The end of the potential core is approximately at the trailing edge.

In this experiment, case three pertains. Note also that the mean velocity plots of the smooth and rough flaps are almost identical in form, except for displacement due to the boundary layer build-up on the rough flap. Based upon these results and results from other configurations it appears possible to reduce turbulence intensity in the secondary mixing region by twenty percent for a 10 percent mean velocity reduction penalty. There is also about a 10 percent reduction in the primary mixing region aft of the trailing edge, however, there is a new source of turbulence generated on the surface of the flap by the turbulent boundary layer. Figure 1h (top plot) shows the turbulence intensity above the flap at the trailing edge. Notice the prominent spike indicating the highly turbulent boundary layer on the rough flap. However, the primary mixing region is slightly less turbulent for the rough flap than the smooth flap. The mean velocity graphs at the bottom of the page are almost identical except for the indication of the thick boundary layer on the rough flap.

Discussion

The results of these experiments indicate that there is a relationship between the boundary layer which is formed on the flap and the intensity of the turbulence measured in the secondary mixing region. The exact nature of this relationship is not fully understood at this time, but it is possible that the thicker boundary layer which is produced by the roughened flap reduces the mean velocity gradient in the secondary mixing region. A comparison of the mean velocity plots for the rough and smooth flap seem to indicate that the smooth flap curve has a steeper slope, hence, a larger gradient, than does the rough flap curve. Because of the very small size of the model, any conclusions that might be drawn about the magnitude of this gradient reduction would probably be misleading. Tests on larger models should yield more reliable quantitative information.

Lilly [4] has shown that for an isotropically turbulent, two dimensional, shear flow that the acoustic power output per unit volume has the following relationship:

$$W \sim \overline{\frac{\partial U}{\partial y}}^{6} \quad \overline{u^{2}} \quad L^{5}$$

where

$W_{..}$ = sound power/unit volume

$\frac{\partial \overline{U}}{\partial y}$ = mean velocity gradient

$\overline{u^2}$ = turbulence intensity

L = lateral scale of turbulence

The turbulence in the secondary mixing region is not isotropic, therefore, Lilly's formula would probably not yield the correct quantitative results, but the qualitative aspects of the relationship should be still valid. Roughening the flap clearly reduces two of these factors, the mean velocity gradient and the turbulence intensity, in the secondary mixing region. However, the effect of roughening is thought to increase the lateral scale of turbulence in the secondary mixing region, although this has not as yet been experimentally verified. If this is so, since L is raised to the fifth power, there will be a limit to the reduction of sound power generation by roughening.

Part II - Cross Correlation

It appears that a possible powerful technique now available for localizing sound sources in the flow field of the jet blown flap is the cross correlation of suitable flow variables with the far field acoustic pressure. Others using this technique have chosen either pressure or velocity as the approriate flow field parameter. As outlined in the previous report, our research effort will employ velocity as the flow field parameter, for a number of fundamental reasons.

1. The hot wire probe used to measure velocity fluctuations is physically much smaller than a suitable microphone.
2. There is no problem with sound generated upstream of the probe as there is with a microphone, and hence, correlating the radiated sound with itself.
3. In the flow field, kinematic measurements are less ambiguous than dynamic measurements.

Test Set Up

A SAICOR 42 digital correlator was borrowed from another research laboratory in order to obtain some practical experience in cross correlation. The test schematic is shown in Figure 2a. The purpose of this experiment was to correlate the velocity fluctuations at various stations in the secondary mixing region with the output of a condensor microphone in the acoustic far field. The smooth .795" flap was used for this test. The control positions on the correlator remained constant during the test and were as follows:

Word Position During Summation	AUTOMATIC
Word Position During Display	2^7
Sample Rate	20×10^{-6} sec.

A 1/2 inch B & K microphone was placed approximately one foot from the hot wire probe at an angle of 60°. The signals were filtered at 20 KC using 1/3 octave filters.

The results are seen in Figures 2b, c, and d. There appears to be strong relative correlation at the proper delay time with an envelope of peaks forming. The computed delay time was about $.87 \times 10^{-3}$ seconds. Since the display position is 2^7, this indicates a rather weak correlation. This is expected since the far field acoustic fluctuations are a very complicated, non-linear function of velocity. There is little else to be said about these results; it is hoped further cross correlations can be done at UTSI which will yield better quantitative and qualitative information.

References

(1) Corcos, G. M., "Some Effects of Sound Reduction Devices on Turbulent Jets", 1959 J. AERO/SPACE SCI. 26, 717.

(2) Yee, Philip M., "An Experimental and Theoretical Investigation Concerning the Aeroacoustic Chara cterisitcs of the Rough Jet Flap", M.S. Thesis, The University of Tennessee, Knoxville, Tennessee, 1974.

(3) Schecker, G. O., "Turbulence and Aerodynamic Noise Characteristics of Jet Flap Type Exhaust Flows", Ph. D. Dissertation, The University of Tennessee, Knoxville, Tennessee, 1972.

(4) Lilly, G. M., "On the Noise from Air Jets", Aeronautical Research Council No. 20376, September, 1958.

TEST SET-UP FOR HOT WIRE FLOW MEASURMENTS

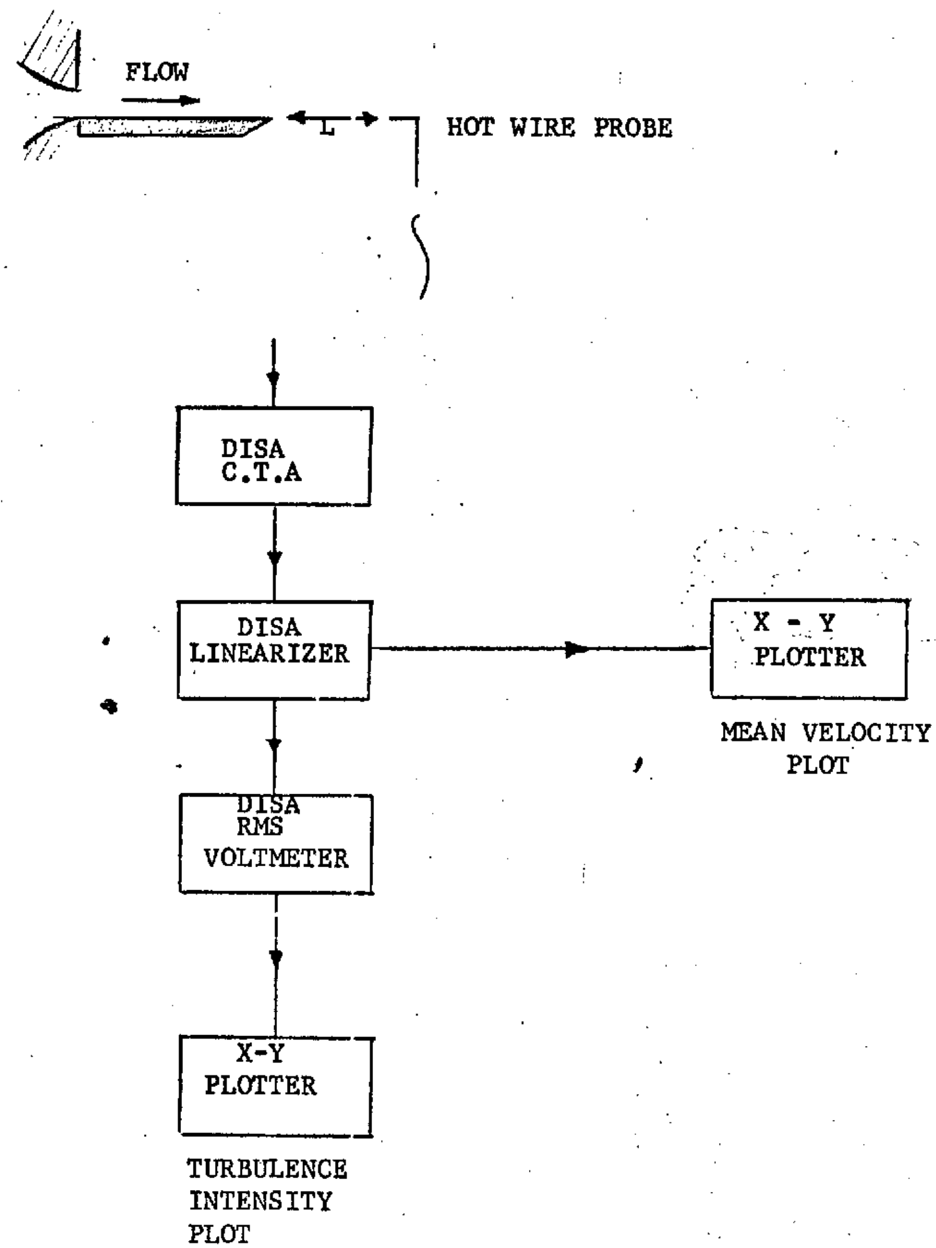
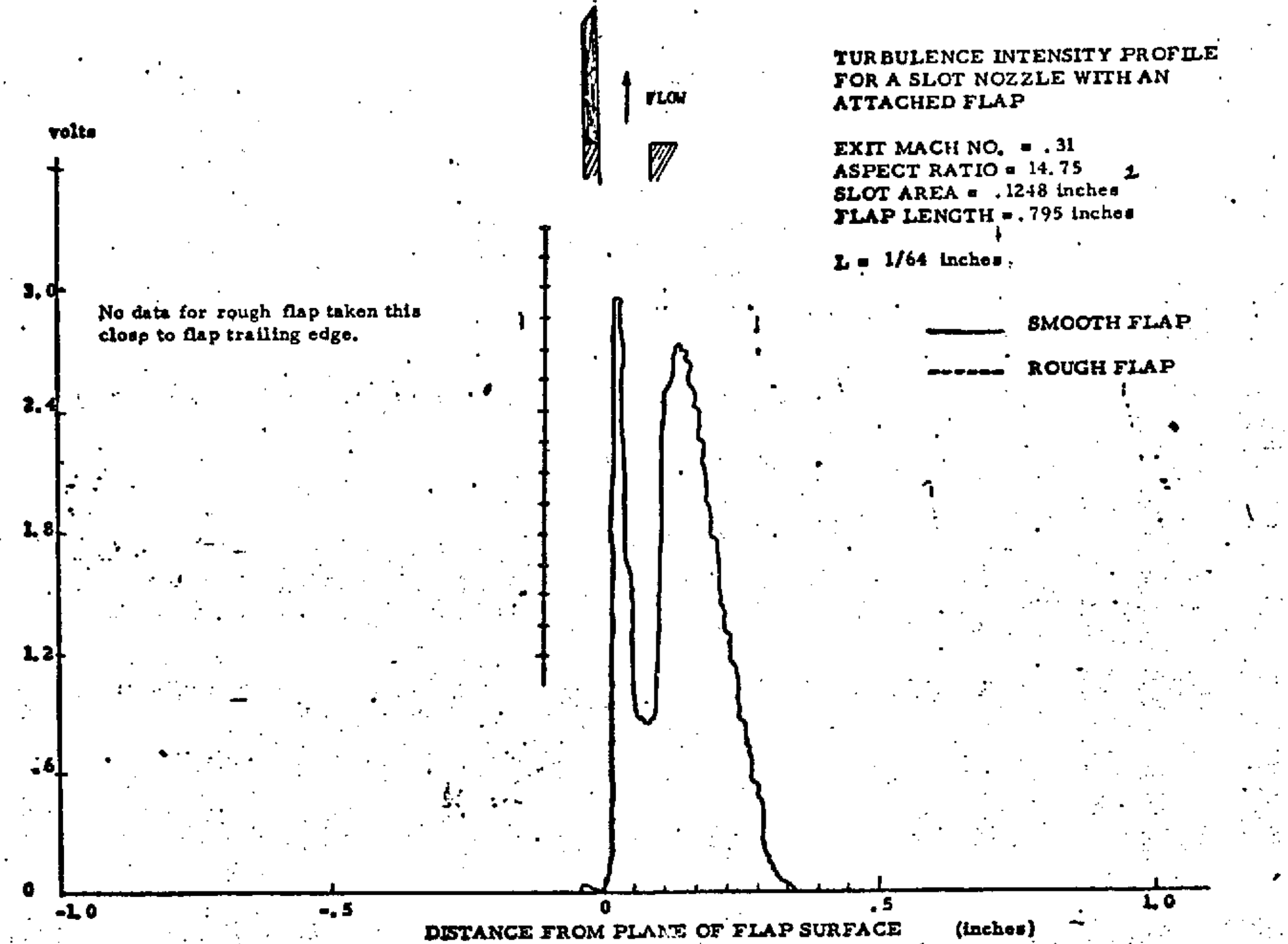


FIGURE 1 a


TURBULENCE INTENSITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches
FLAP LENGTH = .795 inches
1/64 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
No data for rough flap taken this close to flap trailing edge.
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

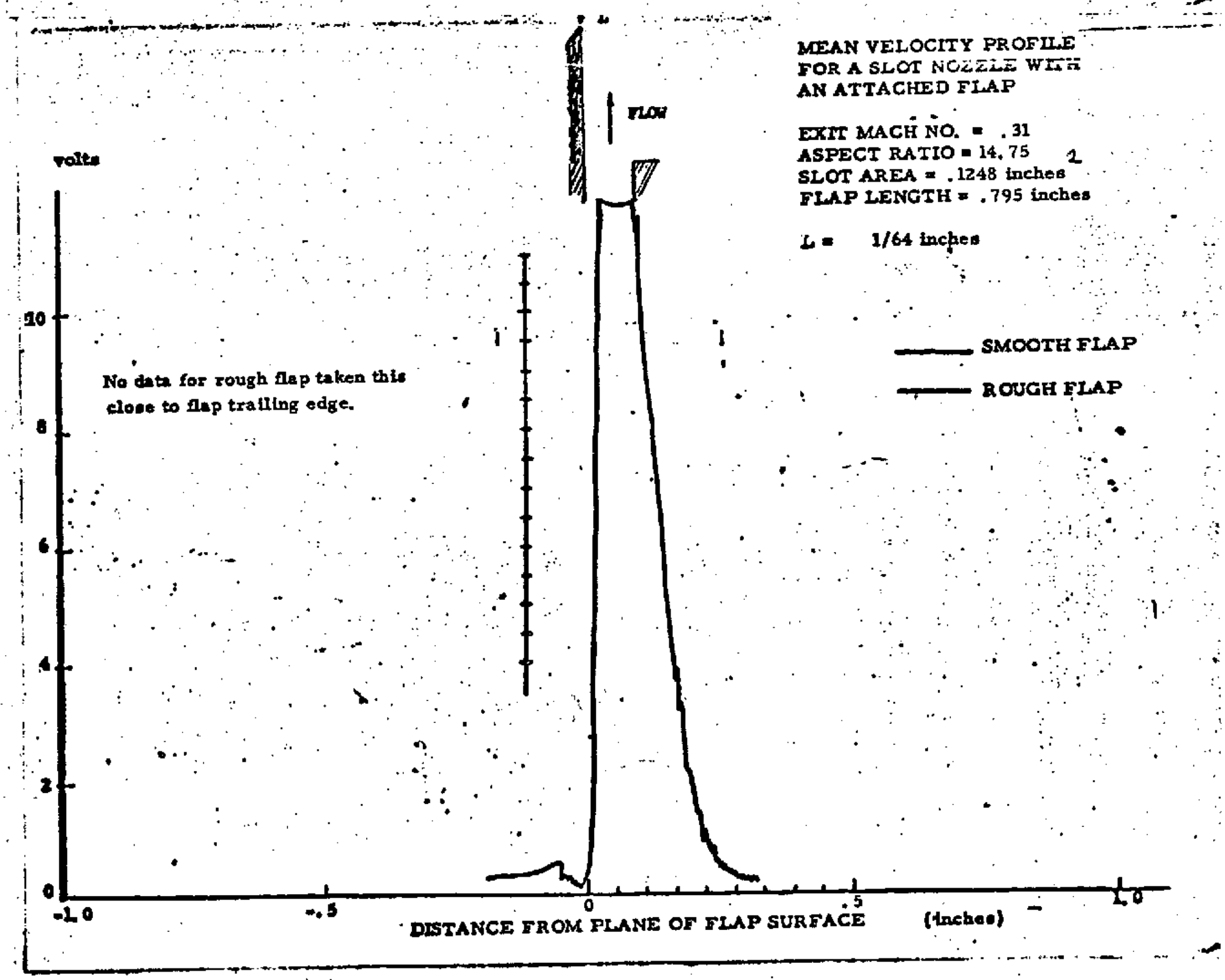
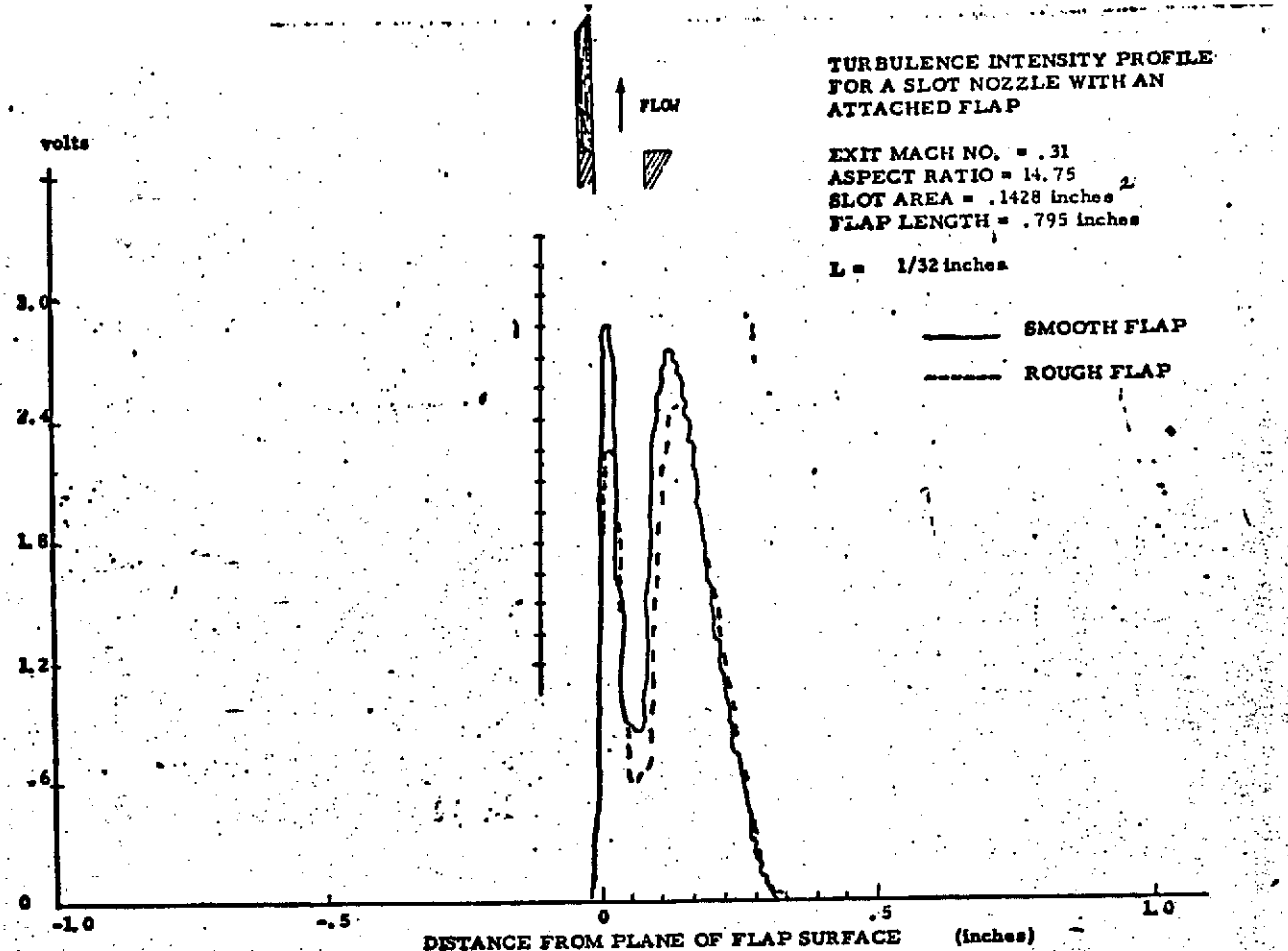

MEAN VELOCITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches
FLAP LENGTH = .795 inches
1/64 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
No data for rough flap taken this close to flap trailing edge.
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1b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EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1428 inches²
FLAP LENGTH = .795 inches
L = 1/32 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

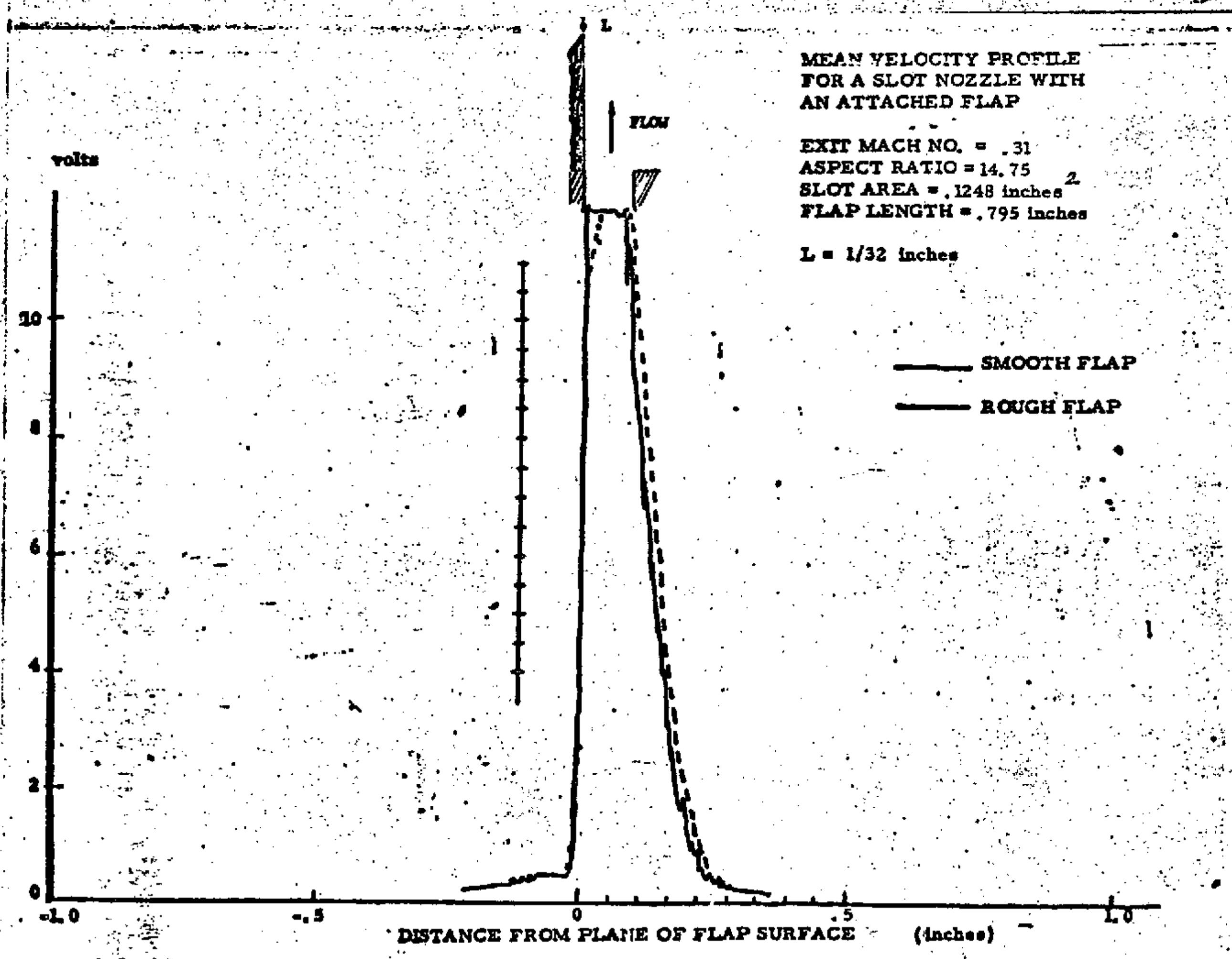
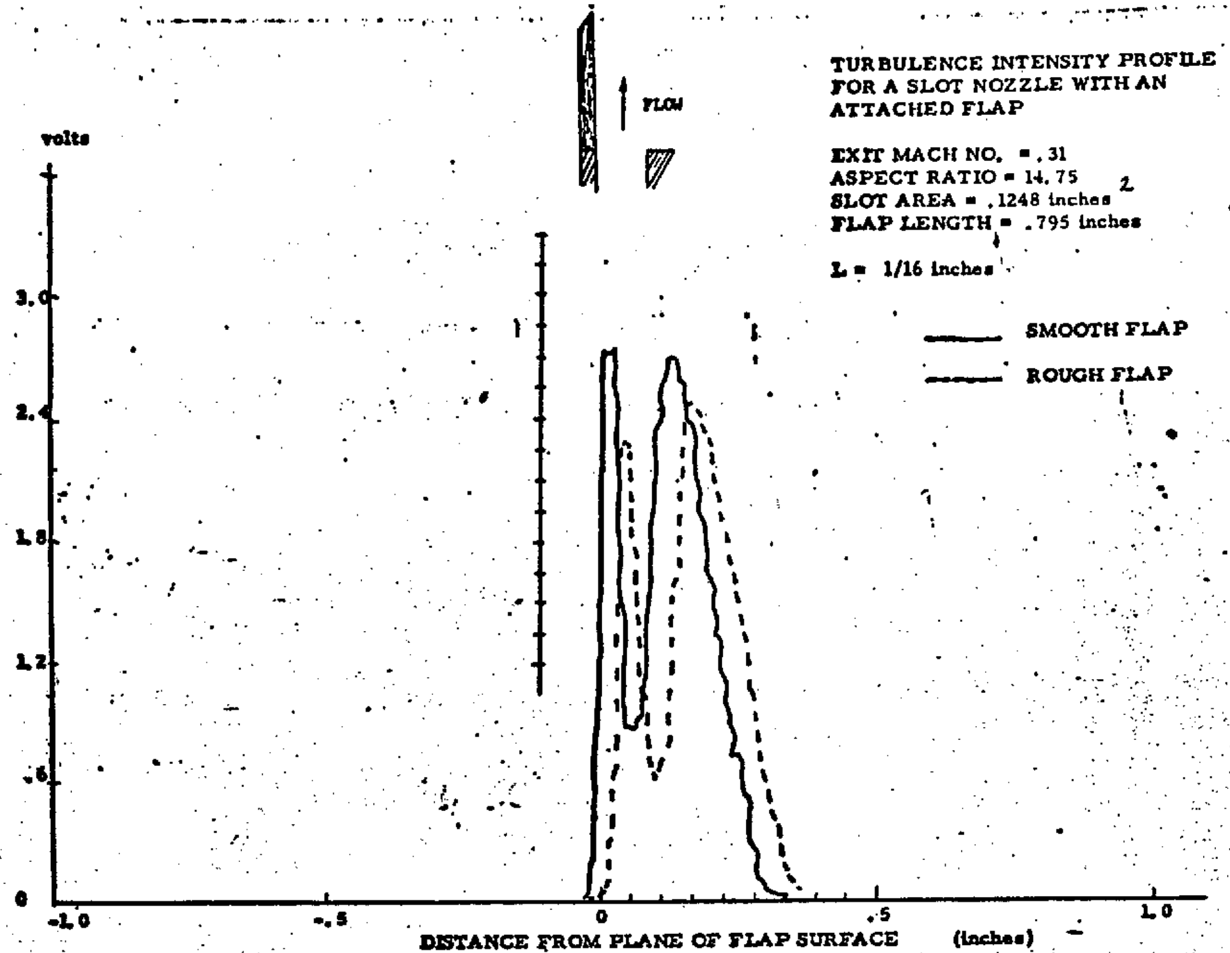
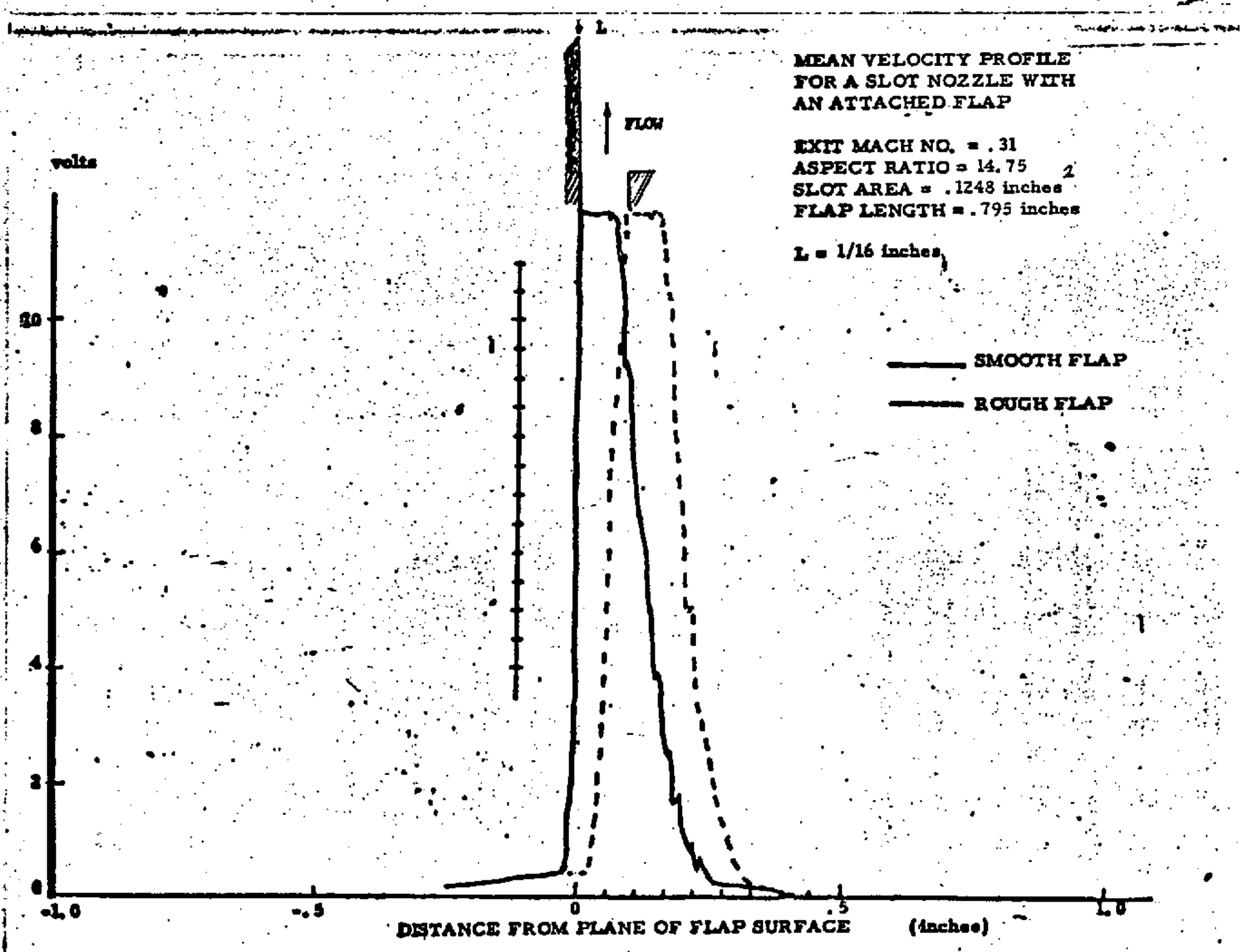

MEAN VELOCITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches²
FLAP LENGTH = .795 inches
L = 1/32 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
L
volts
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1c


TURBULENCE INTENSITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches 2
FLAP LENGTH = .795 inches
L = 1/16 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)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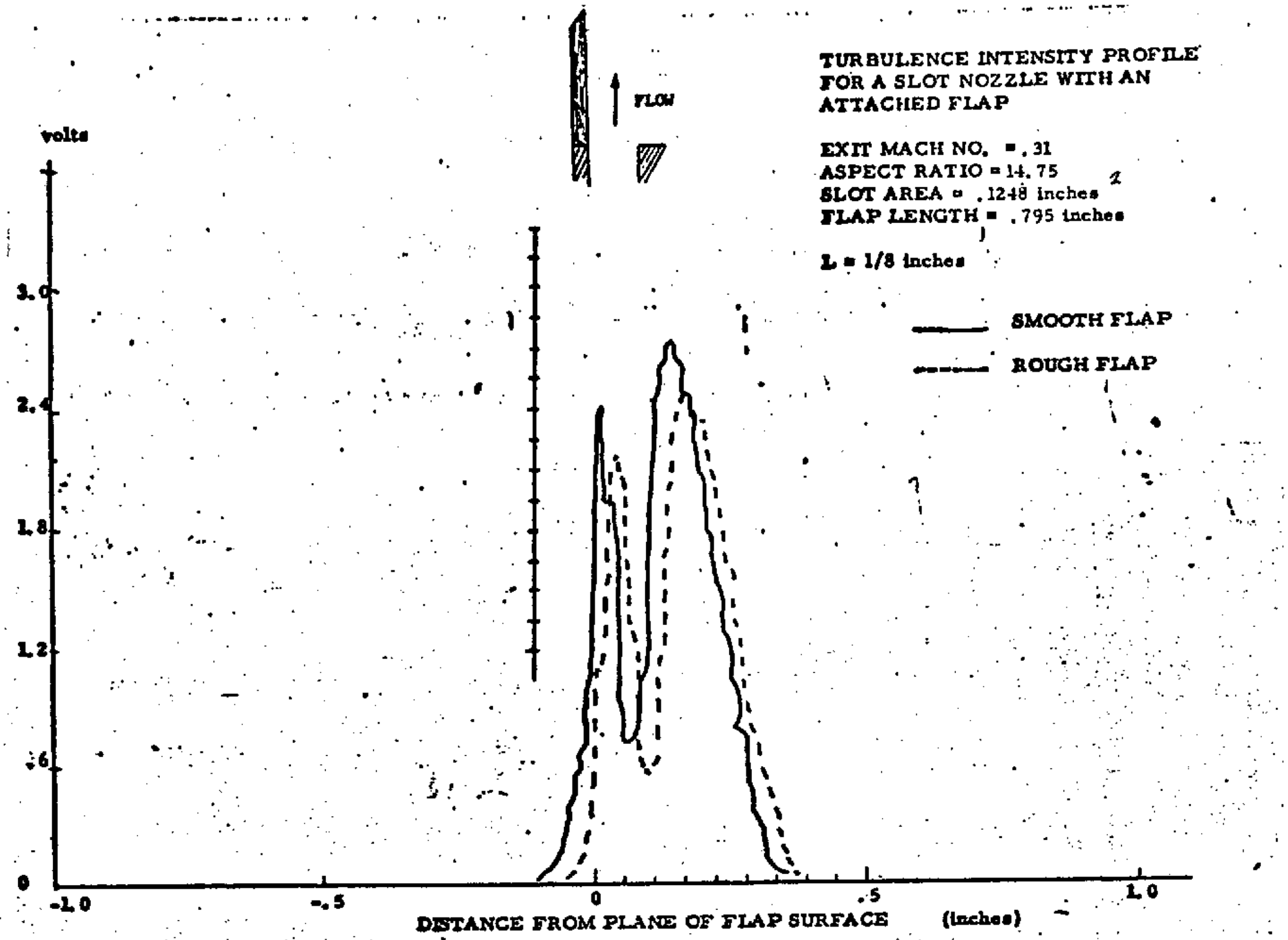
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches 2
FLAP LENGTH = .795 inches
L = 1/16 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
L
volts
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1d


TURBULENCE INTENSITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches²
FLAP LENGTH = .795 inches
L = 1/8 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

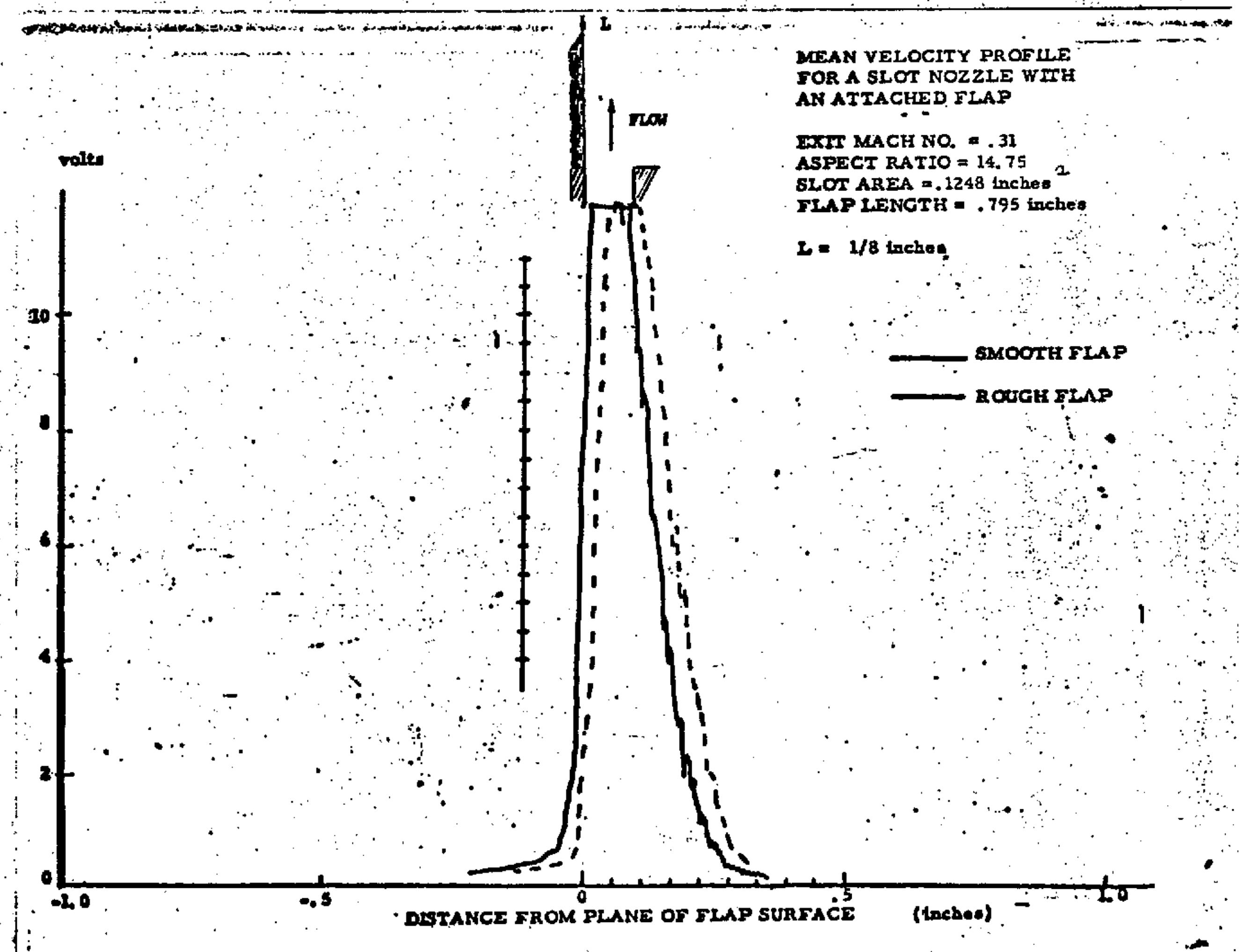
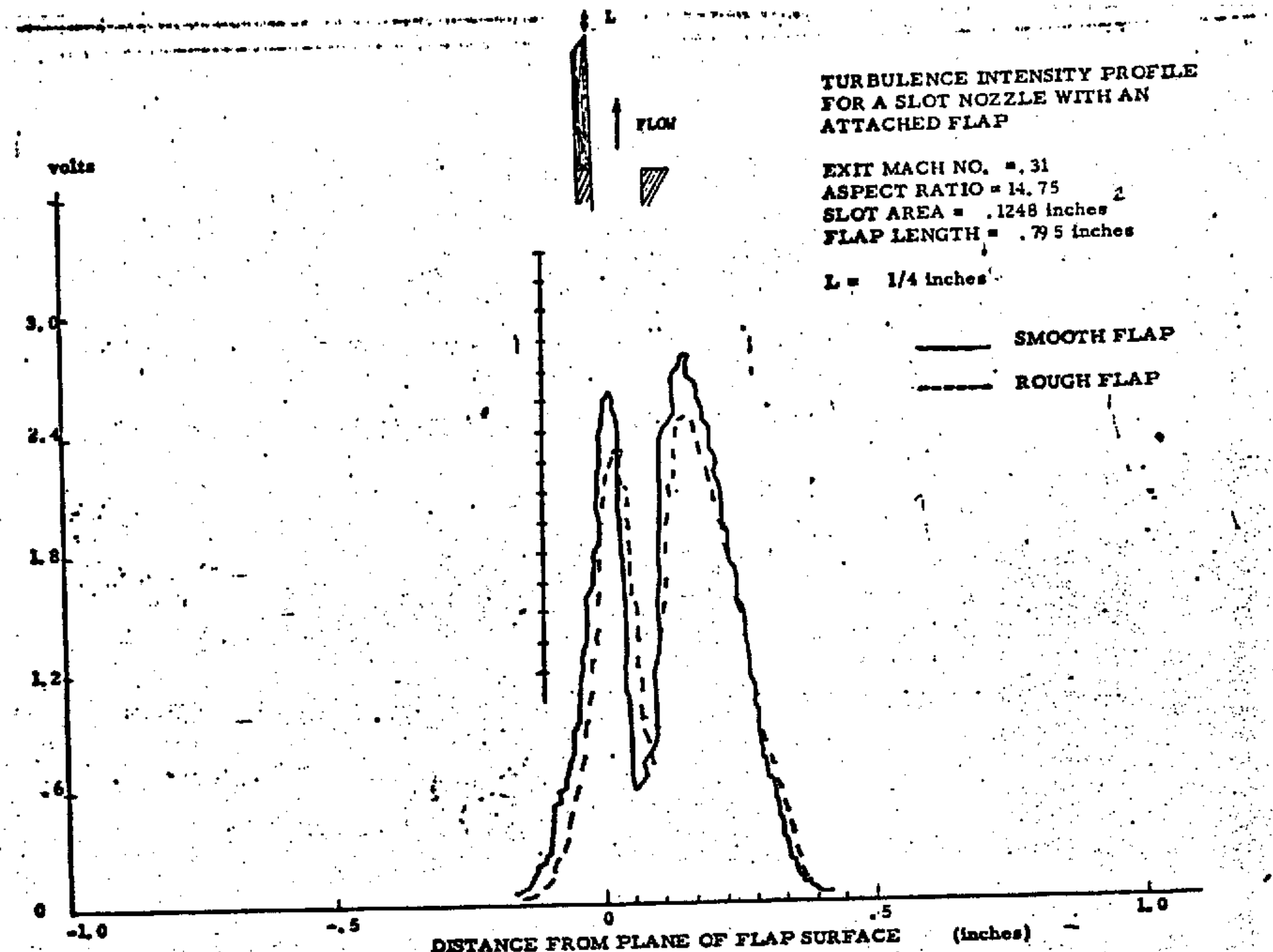
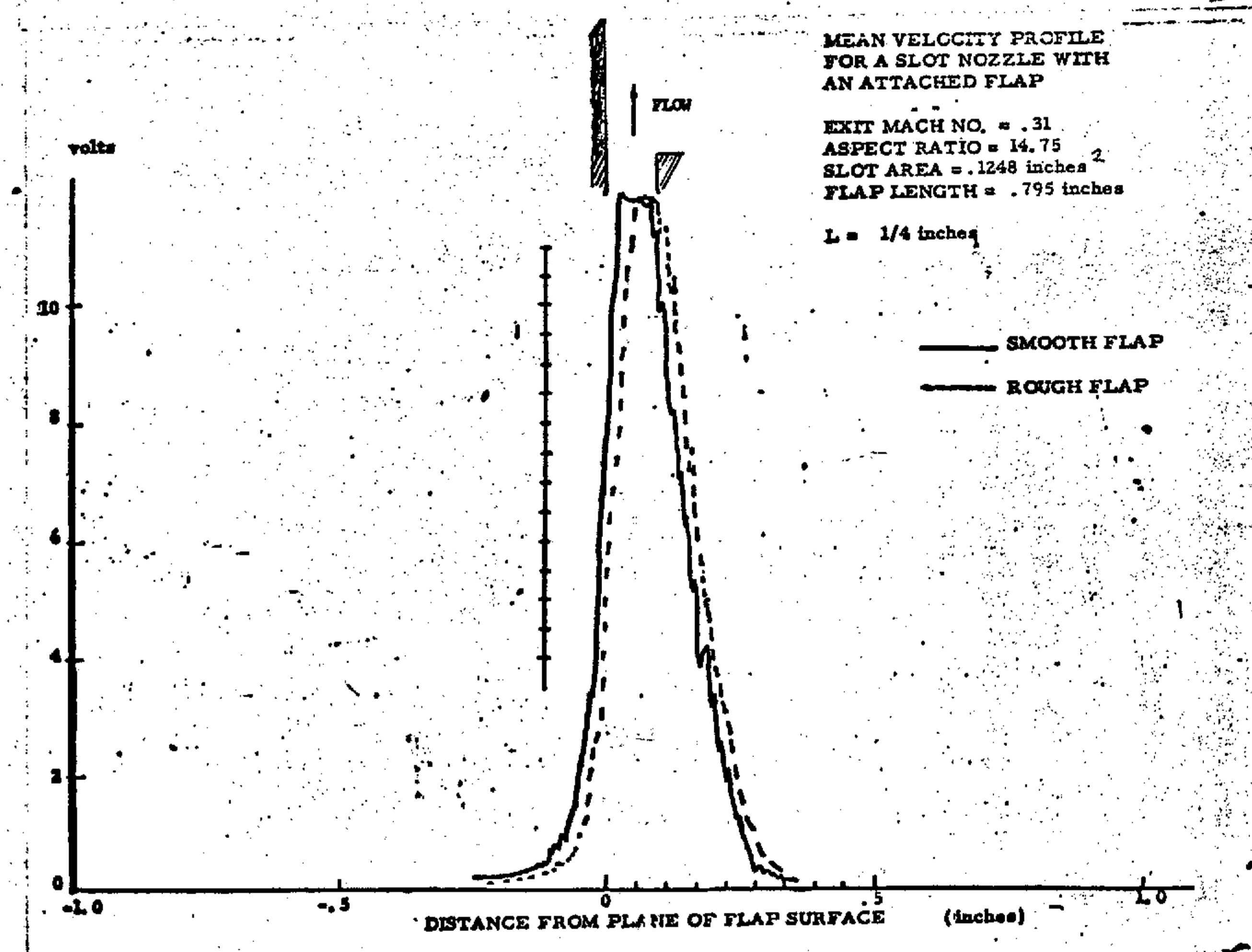

MEAN VELOCITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches²
FLAP LENGTH = .795 inches
L = 1/8 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
L
volts
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1e

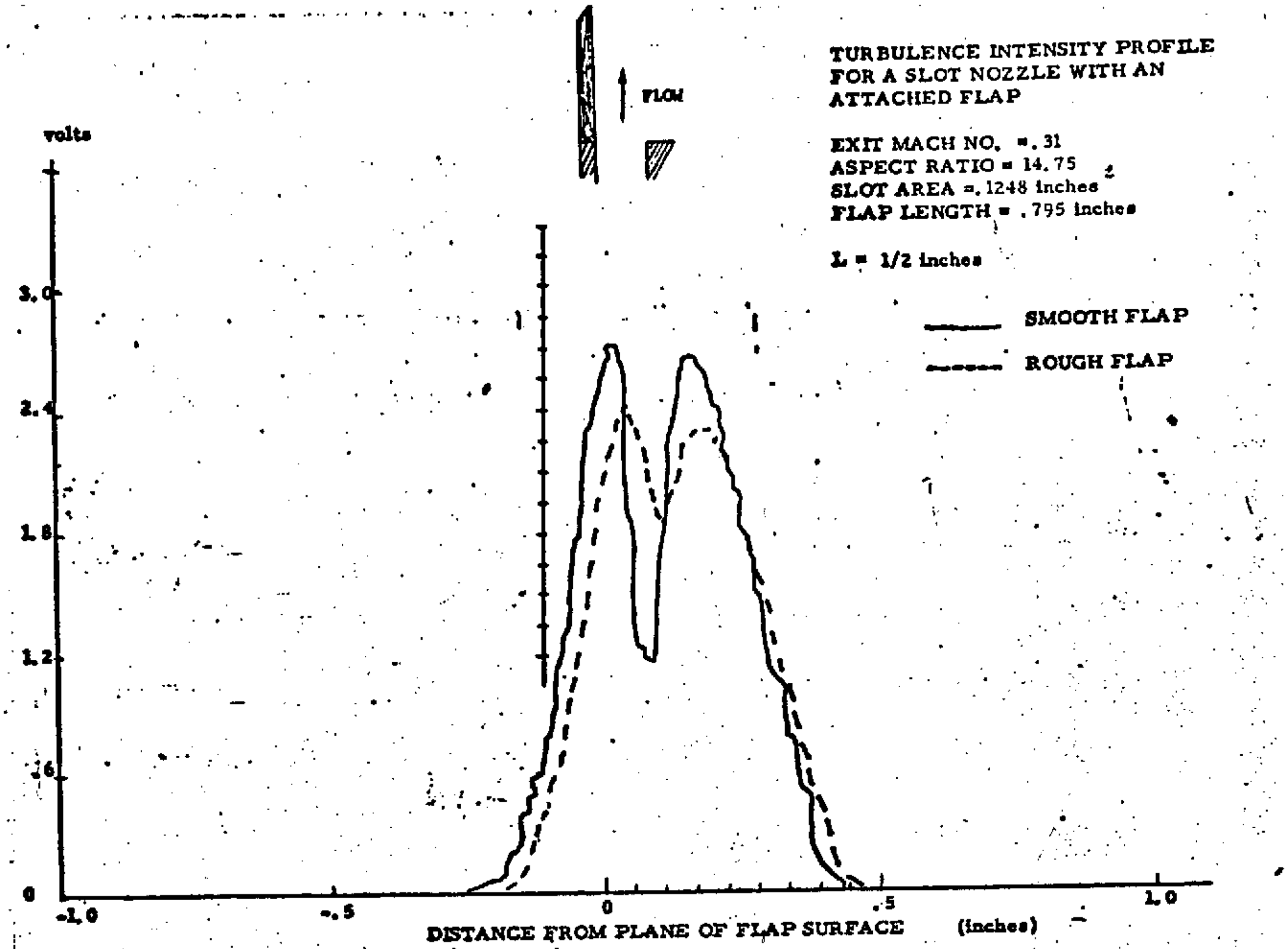


TURBULENCE INTENSITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches^2
FLAP LENGTH = .795 inches
L = 1/4 inches
L
FLOW
SMOOTH FLAP
ROUGH FLAP
volts
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)



MEAN VELOCITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches^2
FLAP LENGTH = .795 inches
L = 1/4 inches
FLOW
SMOOTH FLAP
ROUGH FLAP
volts
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1f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EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches 2
FLAP LENGTH = .795 inches
L = 1/2 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
3.0
2.4
1.8
1.2
.6
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

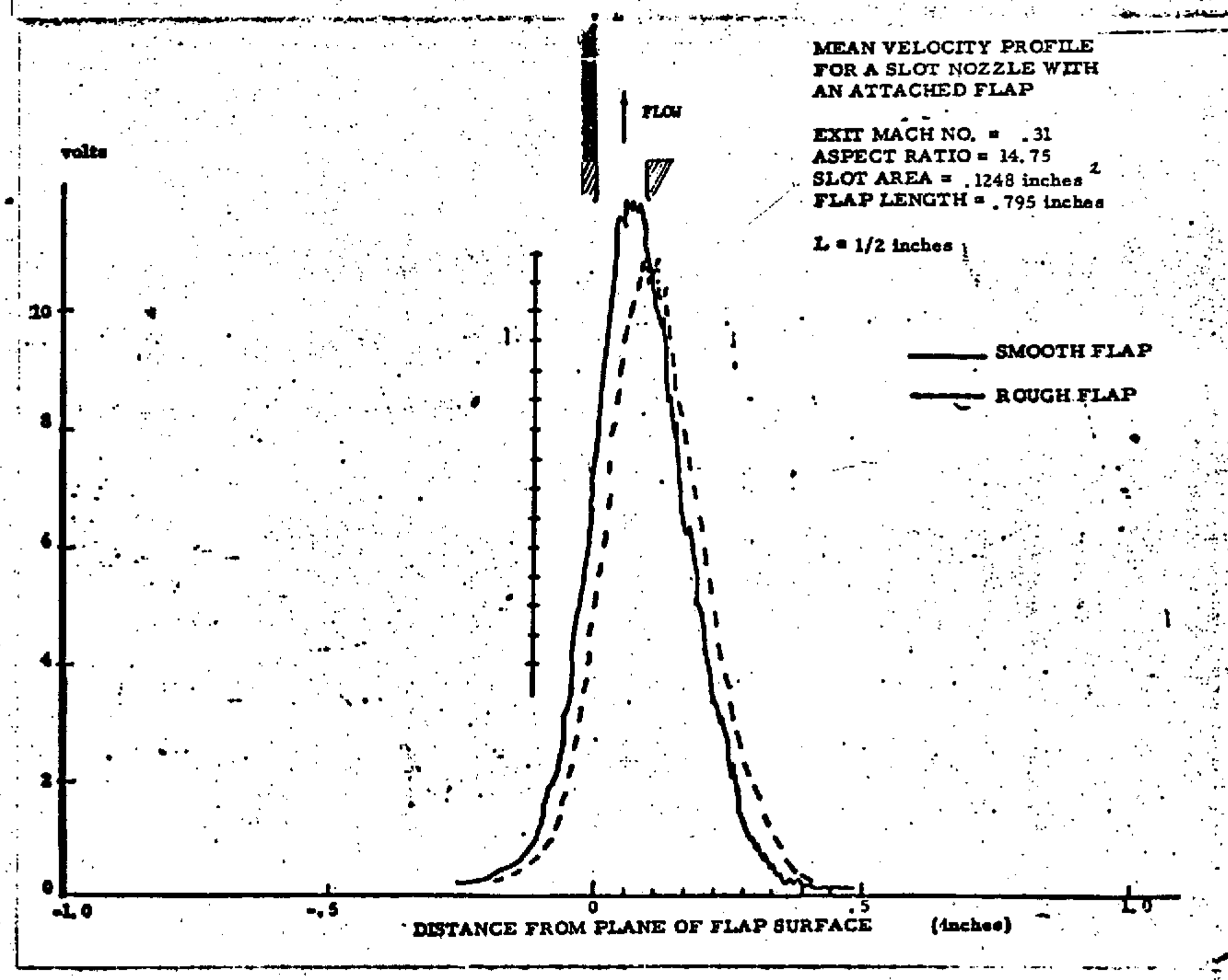

MEAN VELOCITY PROFILE FOR A SLOT NOZZLE WITH AN ATTACHED FLAP
EXIT MACH NO. = .31
ASPECT RATIO = 14.75
SLOT AREA = .1248 inches 2
FLAP LENGTH = .795 inches
L = 1/2 inches
SMOOTH FLAP
ROUGH FLAP
FLOW
volts
10
8
6
4
2
0
-1.0
-.5
0
.5
1.0
DISTANCE FROM PLANE OF FLAP SURFACE (inches)

Figure 1g

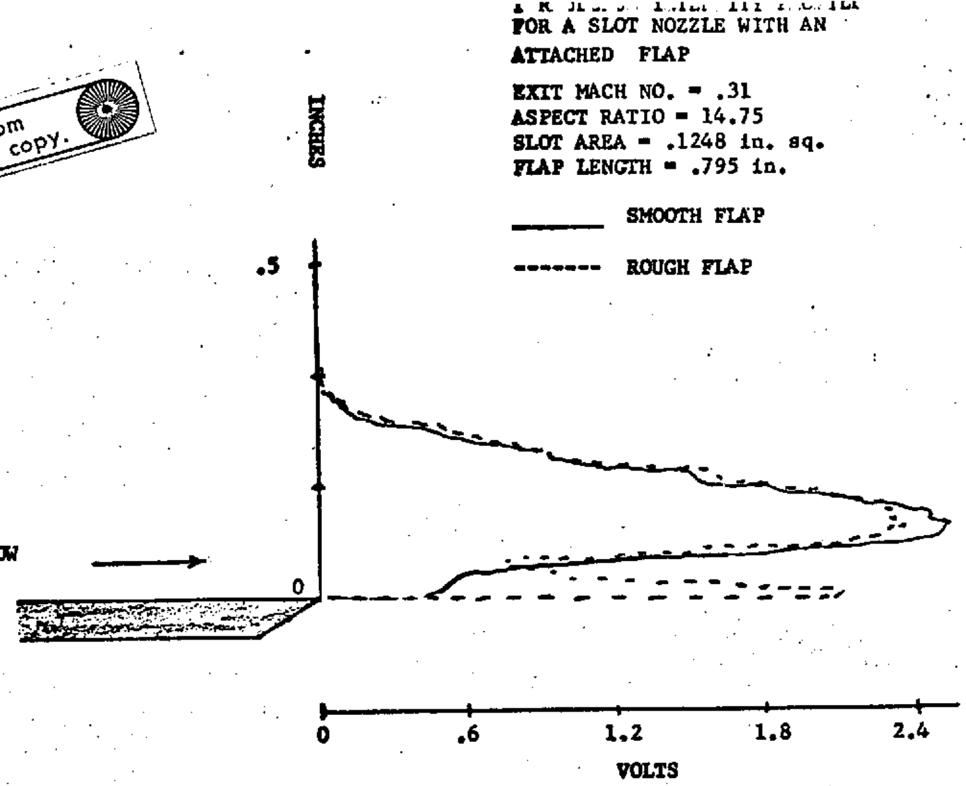
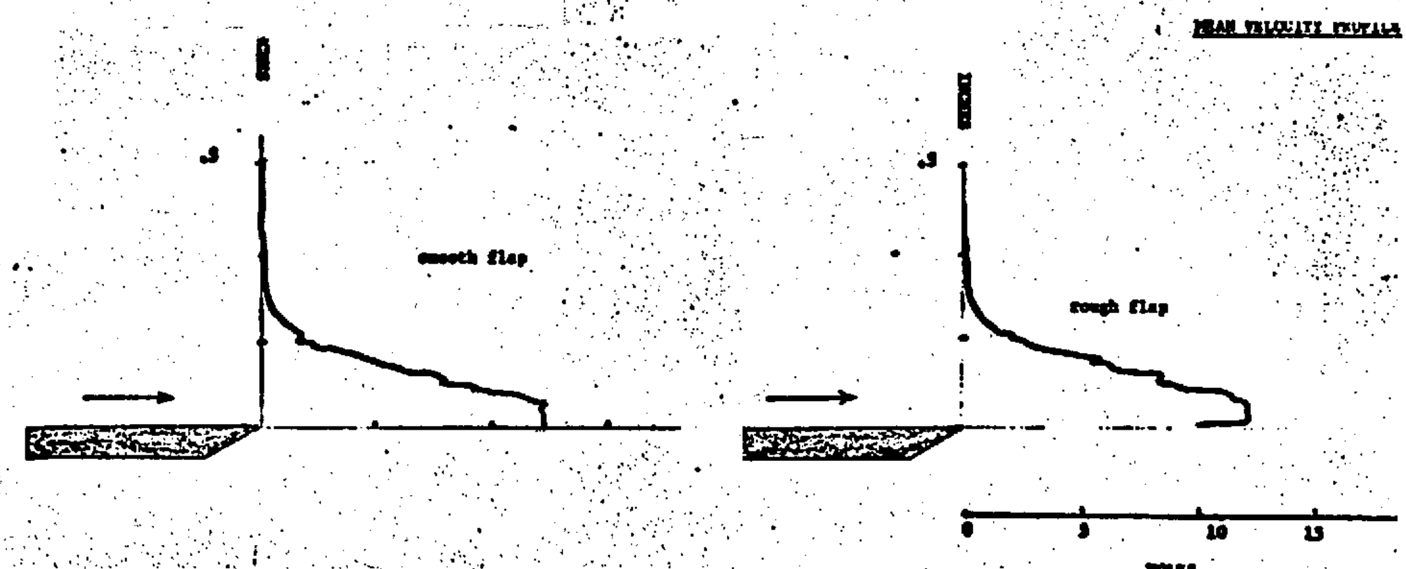


FIGURE 1 h TURBULENCE INTENSITY AND MEAN VELOCITY MEASURED ABOVE THE FLAP PLANE AT THE TRAILING EDGE



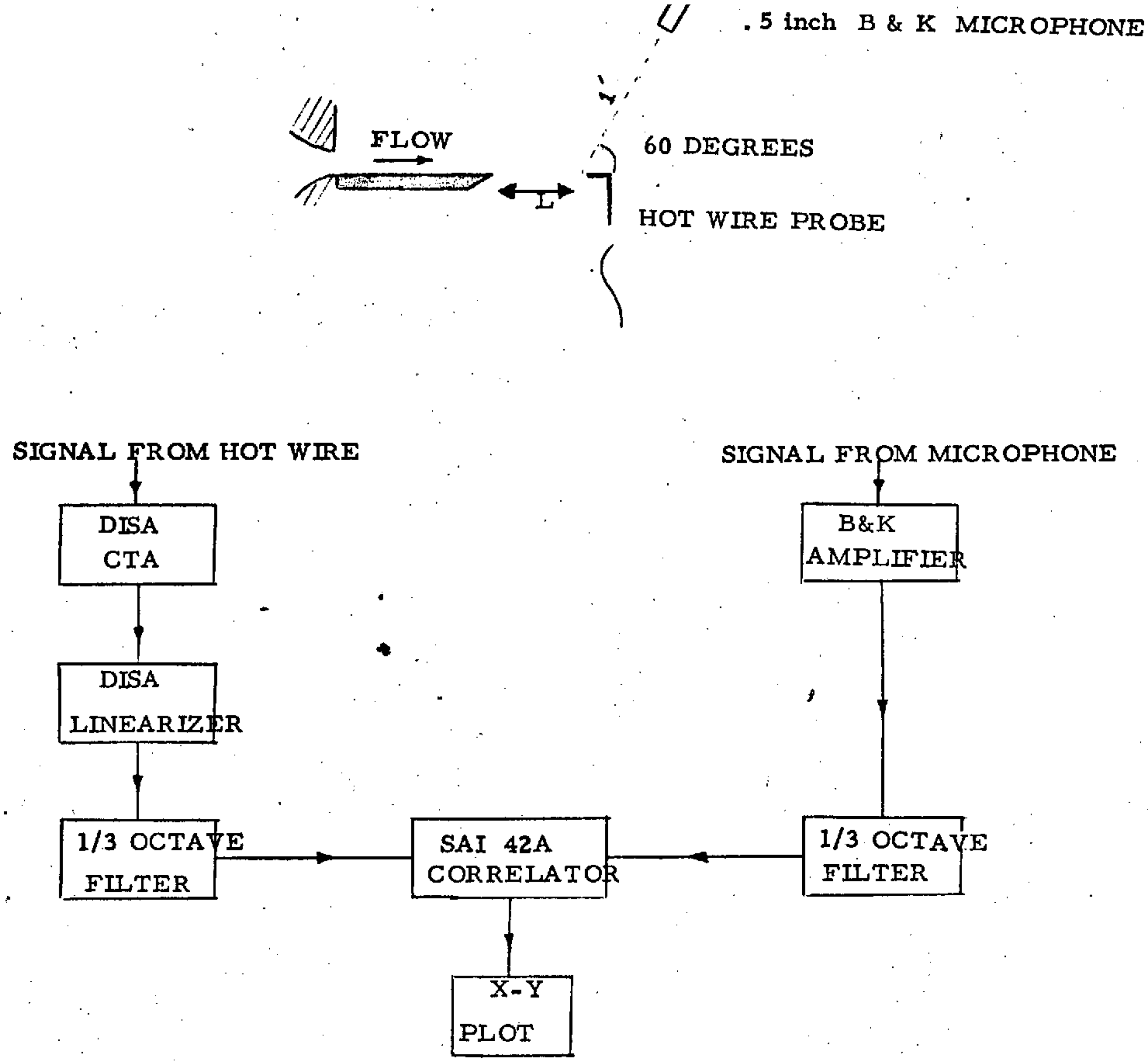


FIGURE 2a SET-UP FOR CORRELATION EXPERIMENT

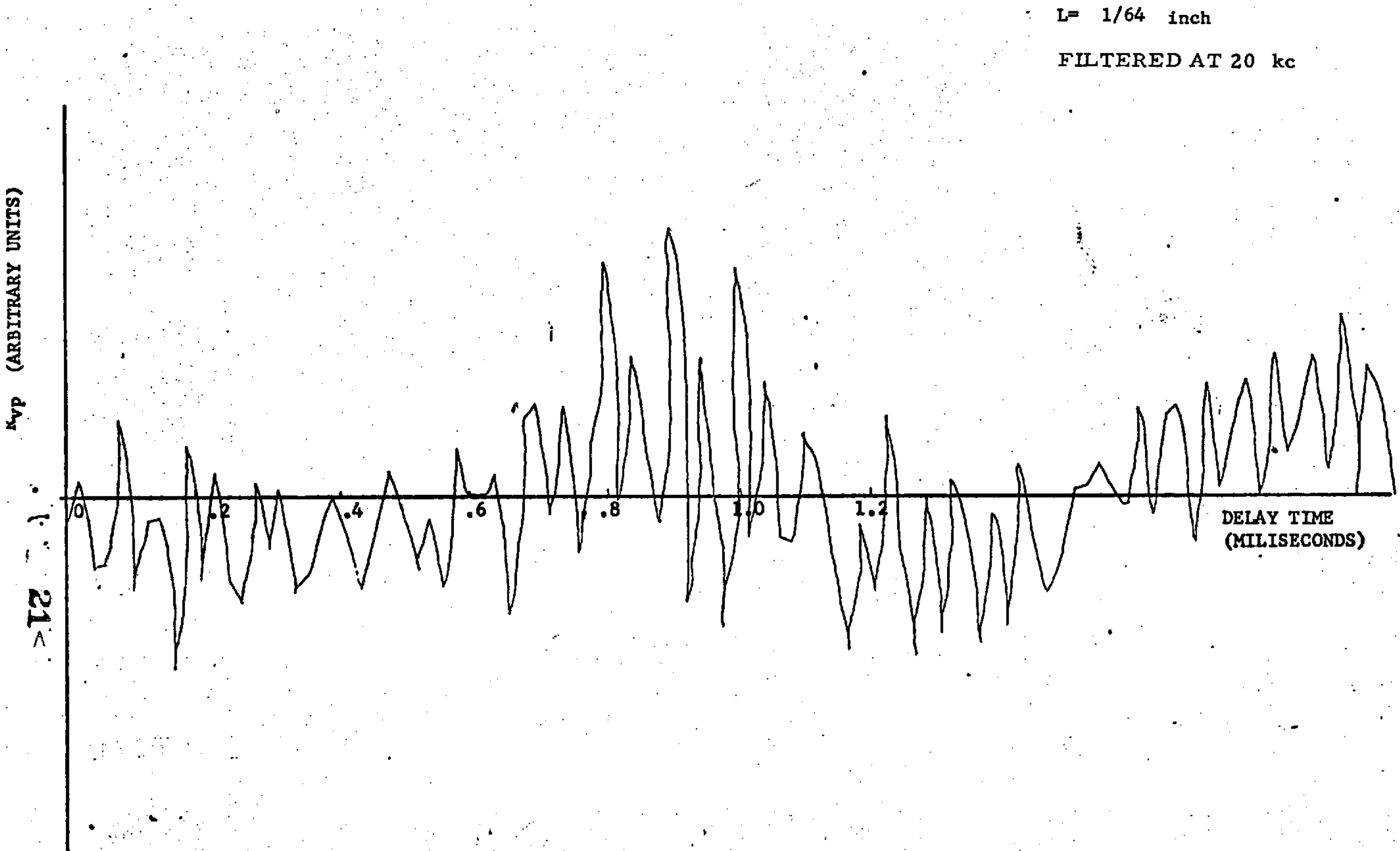


FIGURE 2b CROSS CORRELATION OF FLOW VELOCITY AND FAR-FIELD ACOUSTIC PRESSURE

L = 1/32 inch

FILTERED AT 20 kc

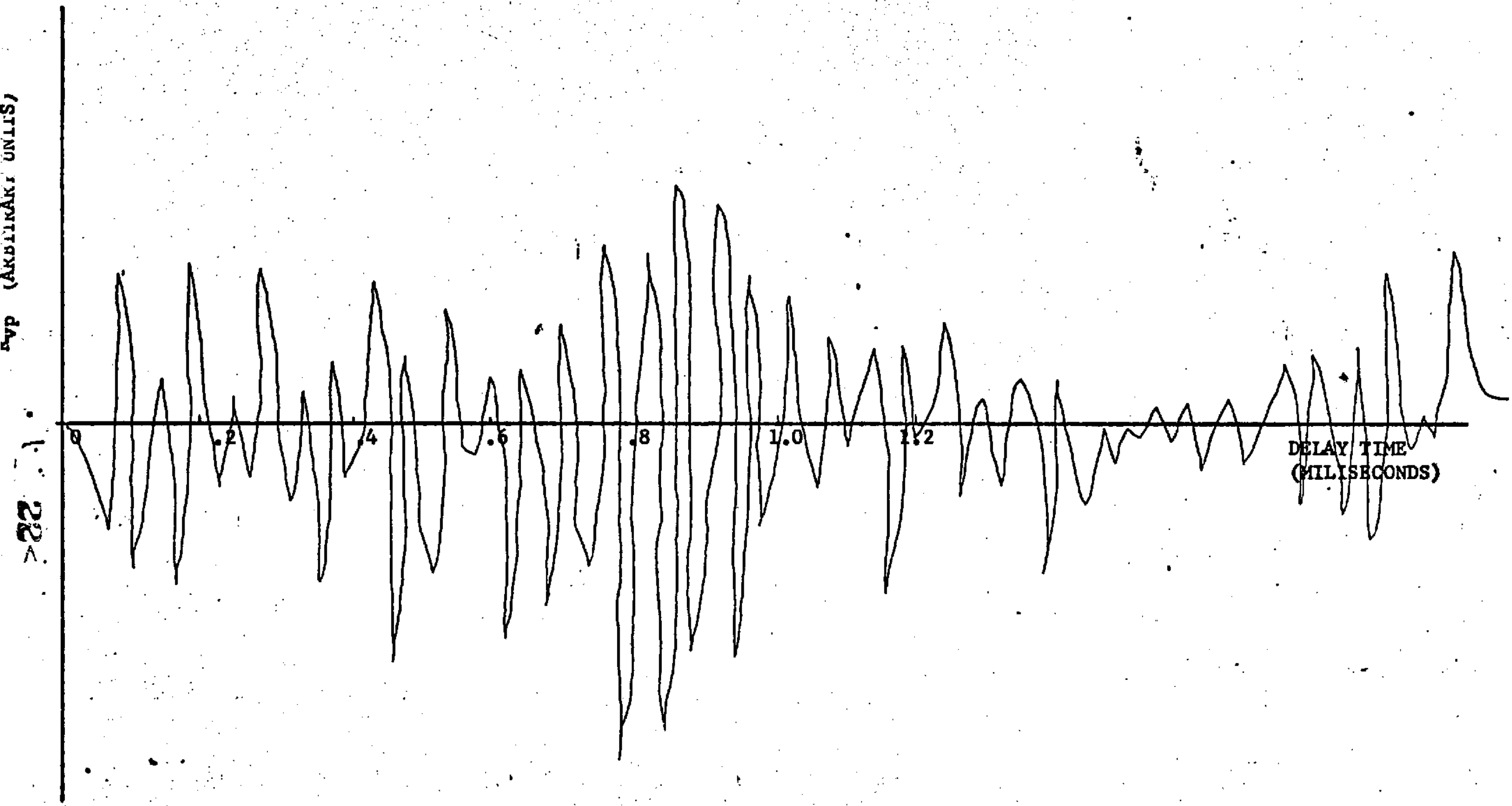


FIGURE 2 c CROSS CORRELATION OF FLOW VELOCITY AND FAR-FIELD ACOUSTIC PRESSURE

L = 1/16 inch

FILTERED AT 20 kc

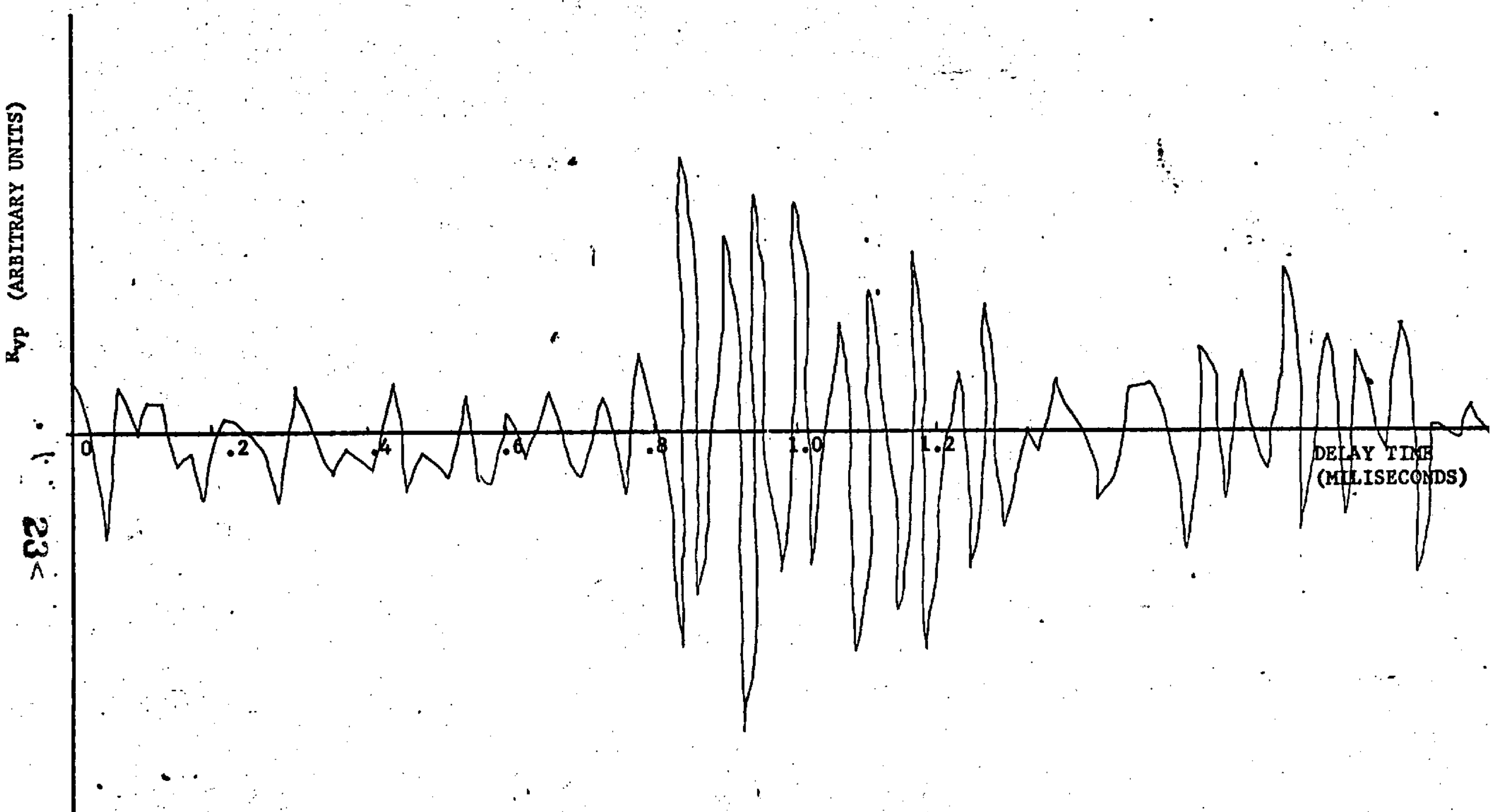


FIGURE 2 d CROSS CORRELATION OF FLOW VELOCITY AND FAR-FIELD ACOUSTIC PRESSURE